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# Information modeling style for belief structures. Notes for developers and information modelers

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# Information modeling style for belief structures

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# Preamble & Motivation

***We want an information model of tracks with these principal qualities***

- Good basis for law enforcement and target prosecution
- Capable of integrating evidence coherently and illuminating important aspects
- Good basis for information sharing
- Effective in reflecting fusion products and documenting pedigrees
  - **Should be able to retain all evidence, inference, and information, when appropriate**
  - **Should support summarization and selective reporting**
- Abstract, stable, general
- Specializable
- Implementable, through logical models to physical models
  - **Polymorphic in the sense of permitting multiple different implementations**
  - **Partially implementable, not requiring total implementation in all contexts**
- Evolvable

***Need to address these different, complementary aspects of information modeling***

- Tracks, as other results of fusion, are uncertain hypothetical interpretations
- The greatest value of tracking comes from identifying threats, i.e. finding that hypothetical interpretations of past and future behaviors as unfriendly and dangerous are believable beyond some threshold of concern
  - **Thus, track models must provide lucid and efficient support for computations of evidence structures supporting hypothetical threat interpretations**
- Life or death decision rest on a correct understanding of the limits of evidence and the nature of competing alternative interpretations
  - **Disconfirming and exculpatory evidence must be accorded special significance in a track model**
- Scientists know that disconfirming evidence should be given greater weight than confirming evidence
  - **Thus, track models must clarify this difference and facilitate the effective use of disconfirming evidence**
- Scientists know that the confirmation of a vulnerable prediction should be given greater weight that the post hoc consistency of some observed event with a hypothetical interpretation

**Thus, track models must clarify this difference and facilitate the effective use of confirmed predictions**

# Belief structure modeling

***Tracks are a special case of belief structures***

***The basic notions of a belief structure***

One or more "propositions" that are alternative interpretations of reality

Each proposition asserts that some predicate is true, some value should be assigned to a variable, or some other sentence is true

Propositions are uncertain

Propositions are evaluated in terms of their degree of belief (aka, probability, certainty, confirmation)

Degree of belief increases with these kinds of events

**The proposition predicts something, that's later observed**

**The proposition provides an explanation for something already observed**

Degree of belief decreases with these kinds of events

**The proposition predicts something, but the opposite occurs (a "disconfirmation")**

**The proposition predicts something which should be observed but isn't (a failure to confirm, a "miss")**

**The proposition is incompatible with something already observed**

***So, the essence of a belief is the predicate or variable value it asserts***

A belief that asserts a single elementary proposition is an "atomic belief"

***A "disjoint belief structure" is a set of competing alternative beliefs***

Each alternative is logically incompatible with the others

***An "hypothesis structure" is a disjoint belief structure that is logically exhaustive***

At least one belief in a hypothesis structure, logically, must be true

A "default hypothesis structure" consists of a belief and its negation

**The negation is often called "the null hypothesis" in scientific experimentation**

***The most likely interpretation of events associated with a disjoint belief structure corresponds to the member belief with the highest degree of belief***

***A "conjoint belief" corresponds to a conjunctive set of belief structures***

The conjoint belief represents the proposition that all of the contained belief structures is true

Conjoint beliefs containing hypothesis structures form AND-OR graphs

**The member belief structures, which are hypotheses, are ANDed**

**The members of the hypothesis belief structures are disjunctive alternatives which are ORed**

***Typical types of composite beliefs***

Joint belief

**A conjunction of a set of atomic beliefs**

*If the members of set B are b1, b2, …, bn, then the conjunction is b1 AND b2 …AND bn*

A time series

**A joint belief in a set of beliefs which interpret events spread over some time interval**

*Normally, the series S consists of temporally indexed beliefs, such as (<b1, t1>, <b2, t2>, …, <bn, tn>)*

**Belief bj applies during time period tj**

An hypothesis structure

**A disjunction of a set of alternative beliefs**

*If the members of set H are b1, b2, …, bn, then the hypothesis structure is b1 OR b2 … OR bn*

A hierarchical hypothesis structure

**A directed tree of hypothesis structures where the root of the tree is the most refined set, containing the largest number of competing alternatives**

**Each node linked to a predecessor generalizes the predecessor's alternative beliefs, collapsing one or more alternatives into a single aggregate belief**

**These structures are often useful for finding the best explanation for observations, which trades off specificity against accuracy**

A classification system

**A hierarchical hypothesis structure that determines what's the degree of belief for various alternative interpretations of a body of evidence presumably emanating from a single entity**

**A human classification system might using biometrics from one source to determine what name to call the person, what sex the person is, what nationality the person has, or so forth.**

A dynamic model structure

**This is a belief about the way an entity behaves**

*Behavior can be modeled in different ways*

**It usually is associated with a history, a time series of observed states**

**It usually makes possible the computation of future possible states, one or more time series of predicted observable states**

Inference structure

**This is a belief structure containing multiple beliefs that reflects how some beliefs imply other beliefs**

**Sources of inference vary, and can include:**

*Definitions, as when a specific value implies a more general one*

*Facts, as when one belief is certain to imply another*

*Causality, as when one event is believed to cause another*

*Knowledge, as when one belief usually can correctly predict another*

**Inference structures regularly embellish beliefs and make it possible to make richer use of evidence**

Part-whole aggregation structure

**A special kind of inference structure that asserts several individual entities are part of one logical or physical entity**

**Example is several people are part of a crew, or several pallets are part of the cargo on board**

**The logic for aggregation may be of any of the types that inference structures allow**

Affiliation or association structure

**A special kind of inference structure that asserts some entities are affiliated with another entity, where affiliation is a kind of behavioral aggregation**

**Example is the crew is affiliated with a vessel and the vessel is affiliated with an insurance carrier**

## Evidence Management

***Observations of events deemed to bear on the degree of belief constitute "evidence"***

Evidence can be pro or con, confirming or disconfirming

**If a belief implies an event, observing the event confirms the belief**

**If a belief implies the negation of an event, observing the event disconfirms the belief**

***Evidence is arrayed for and against competing beliefs in an hypothesis structure***

A consistent array of evidence associates every element of evidence with all competing beliefs that it confirms or disconfirms

A single observation might confirm or disconfirm several beliefs

***Normally, we are interested in effectively gathering and applying all evidence relevant to important kinds of hypothesis structures***

One example, is the friendly-vs-unfriendly interpretation of a track

Another example is the Legitimate Crew vs Illegitimate Crew interpretation of a track's crew

***In addition, we want to maintain beliefs that do an excellent job of explaining most of the observed events***

This means confirming interpretations that account for most data

This helps identify anomalous events, that are incompatible with prevailing interpretations or normal behaviors

## The role of meta-information in track management

***Meta-information can serve multiple purposes***

As in data dictionaries, describes the names and types of modeled elements

In decision-making systems, including fusion, characterizes the quality of information and information products

**Specifically needed are characterizations of:**

*Belief structure and contents*

*Degree of belief*

*Evidential support for beliefs*